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# Decision Support System Using Fuzzy AHP and Activity Based Life Cycle Costing

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**ABSTRACT**

Decision making in many industries is complex due to a degree of inherent uncertainties. These uncertainties can be quantitative or qualitative. Taking into account only quantitative factors like cost doesn't bring a convincing decision making analysis. In this paper two methods; Activity based life cycle costing (ABC-LCC) and Fuzzy analytical hierarchy process (FAHP) are used to determine the quantitative and qualitative uncertainties in the decision making. The final decision is made by integrating the output of the above methods using weighted sum method (WSM). A decision to buy a new pump or to continue with the old one is analyzed. It is found that using ABC-LCC method the decision is to continuing with the old one, however when FAHP is used the decision is to buy a new one. The integration of these two method using WSM it is found to select pump A, that means the final decision is to continue working with the old pump rather than buying a new one.



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## INTRODUCTION

Decision making in many industries is complex due to a degree of inherent uncertainty. These uncertainties can be quantitative or qualitative. Taking into account only quantitative factors like cost doesn't bring a convincing decision making analysis (Jesse A.*et al*., 2010). Due to this increasing complexity and the need to incorporate all type of uncertainty a decision support model should be developed to aid the process.

One of the most powerful quantitative decision making tool is life cycle costing (LCC). Life cycle cost analysis is used as a decision support tool to aid decision makers to propose, compare, and select the cost effective alternatives for maintenance, renewal, and capital investment (Rahman and Vanier, 2004). In order to determine accurate and efficient LCC, the costing method used has high impact. The costing method used needs to have the ability to grip the uncertainties raised, since predicting the future is full uncertainties. Activity Based Costing (ABC) model deals with all the activities that will incur a cost and it has the best capability to deal with the uncertainties (Emblemsvåg and Bras, 2001). ABC methods are modern methods for estimating cost regarding clear methodology and easier to compute.

Due to its convenient way to quantify the qualitative attributes of the options presented, hence removing subjectivity in the result analytical hierarchy process (AHP) is highly chosen as a qualitative decision making tool (Tiwari, 2006). In the traditional AHP method, the subjective descriptions of reviewers' decision are often corresponding to exact value. As a result, the vague descriptions are often ignored by the researchers. In order to make the analysis results more reasonable, using fuzzy set theory to deal with the problems of fuzziness is very important (Yu, E. L, 1995). Fuzzy theory is based on fuzzy sets, which is the expansion of crisp sets. Fuzzy theory overthrows the two/dual value (yes or no) so that its multi-value could be pressed close to reality.

FAHP and the LCC have different measurement unit the first one is in percentage and the second one is in dollar. Another method is needed to integrate their values into a single level of decision making. Weighted sum model (WSM) is the simplest and most effective method for this application (Triantaphyllou. *et al*., 1997). Weighted summation makes the 'incomparable' attributes comparable, prioritizes them by assigning weights and finally reduces the amount of information by aggregating the weighted standardized scores. This process provides not only a ranking of the alternatives, but also comprehensibility and the strengths and weaknesses of the policy alternatives (Quinn. et.al, 2007). Thus in this study a decision support model which incorporate quantitative and qualitative uncertainties will be developed by integrating ABC-LCC and FAHP.

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***Methodology:***

In this section the develop decision support model is discussed in detail. The general framework is shown below in Fig 1.

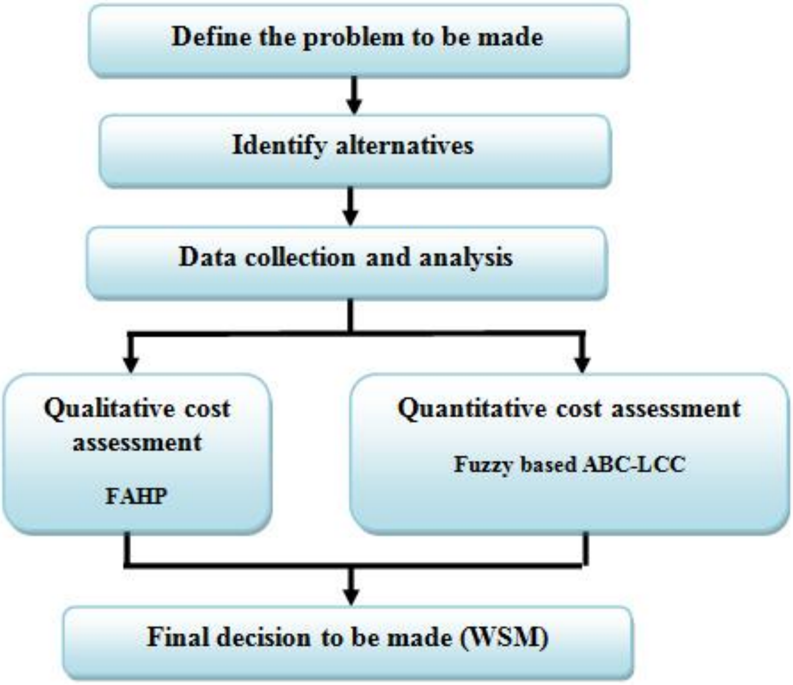


**Fig. 1:** Schematic representation for decision support model.

### *A. Define the problem and Identify alternatives:*

Any decision making process begins with the identification of the problem under investigation. There are different alternatives with, pros and cons, which are helpful in solving the identified problems. Analyzing the pros and cons has to be the first step.

### *B. Data collection and analysis:*

The quality of decision support model is highly affected by the available data. In terms of time, effort, and resources consumed, collection of data is a major part of a ABC-LCC and FAHP study. Some of the typical data sources for LCC are basic accounting records, cost reports, historical databases, functional specialist, technical databases, cost proposals, contracts and other information system for LCC. Some of the types of data collected from these sources are purchase price, direct labor, lost production, spare parts maintenance, material cost, cost of preventive maintenance schedule, cost of repair, life of equipment, unscheduled breakdown cost, mean time between failure for corrective maintenance (MTBF), production delay hours, Mean time to repair (MTTR), repair time, and down time. In AHP, the decision maker expresses judgments in terms of pair wise comparisons through questionnaires, interview and panel discussion and the verbal judgments will be translated into numbers.

### *C. Fuzzy Analytical Hierarch process (FAHP):*

Once the problem and the alternatives are identified the next step in FAHP is to decompose the entire problem into hierarchical structures which has three levels; the goal of the decision; the criteria; and the options. The judgment of the decision maker will be translated into numbers. In FAHP this numbers are expressed in triangular fuzzy number.

The membership function of a triangular fuzzy number lies in the interval of [0, 1], & it is expressed as:

$$\mu_M(x) = \{(x/m-l)-(l/m-l), \ldots\ldots x \in [l,m], (x/m-u)-(u/m-u), \ldots\ldots x \in [m,u]. \tag{1}$$

where $l \leq m \leq u$, u and l are the upper and lower value of the modal m of the fuzzy triangular number which is denoted by (l,m,u) respectively. If l=m=u, it becomes the ordinary number (i.e. non-fuzzy, crisp). The support of m is the set {xϵR/l,x,u} where R is a real number and $\mu_{A(x)}$ is the membership function. There also involve an operation in a fuzzy matrix. The sum, subtraction, and multiplication of a two triangular fuzzy number are similar to crisp numbers the only different operation is on the inverse. Extent analysis method is used to consider the extent of an object to be satisfied for the goal, that is, satisfied extent. In the method, the ‘‘extent’’ is quantified by using a fuzzy number. For further details on the method of priority calculation and extent analysis, refer to (Tiwari. N, 2006), (Chang, 1996).

***D. Activity based life cycle costing:***

The first step in ABC-LCC is forming activity hierarchy, when the hierarchy is made an activity network is formed. The ABC-LCC model is extensive. In ABC cost estimating techniques it is necessary to identify each activities in all the stages, since the principle of activity based costing is that products or services consume activities and these activities consume resources that generate costs. This makes the identified activities to be cost drivers (Emblemsvåg, 2001). Presenting all the activities and the drivers will be a tiresome. Therefore, only the high impact drivers needs to be identified, these are, directs labor, number of components for replacing failed parts, and running hour. For identification of the relationship between activity and resource drivers due to the expenditure of activity depends on a variety of drivers, it is convenient to use historical data from which the relationship can be established.

In this section the probabilistic approach, LCC model is developed. The general model for the LCC is therefore as shown Eqn 2.

$$LCC = C_{aq} + C_{op} + M_c \tag{2}$$

where $C_{aq}$ is acquisition cost, $C_{op}$, is operating cost, $M_c$ is maintenance cost. The final future cost will be discounted to the present by using the interest rate over the appropriate study periods.

$$NPW_i = C_{aq} + \sum_{j=1}^{N_i} [C_{op} + M_C] * 1/(1+i)^{k_{ij}} \tag{3}$$

where $NPW$ is net present worth. $N_i$ is the number of irregular future costs; $k_i$ index for each compounding period; and $i$ effective interest rate which is equal to 8% is discount rate.

***E. Weighted sum model:***

The result which is going to be found from the qualitative (FAHP) and from the quantitative (ABC-LCC) has different dimensional value which is priority and cost. The final decision should integrate these two assessments in order to make all rounded decisions. Weighted sum model (WSM) is the simplest and most effective method which is used to compare the incomparable attributes, priorities them by assigning weights and finally reduces the amount of information by aggregating the weighted standardized scores (Riantaphyllou, 1997). This process provides not only a ranking of the alternatives, but also comprehensibility and the strengths and weaknesses of the policy alternatives (Quinn. A. et.al.,2007). Normalization requires consideration of different characteristics for each modular result. High values are preferred for these results. The Equation shown below calculates the normalized vales of modular results. Symbol ($a_{high}$) is used for the normalization of high value preferred results

$$ah_{ighi} = \left[ \frac{R_i}{\sum_{i=1}^{n} (R_i)} \right] \tag{4}$$

where $R_i$ is a result corresponding to an alternative from each modular assessment and n is the number of alternatives. The relative importance of each modular result is expressed as an interval value from 0 to 1. The sum of the relative importance must be equal to one. This relative importance is used as a weight factor $W_j$ in the Equation below, which is used to calculate the overall value S of each alternative. The sum of weighted normalized values of all alternatives must be one. The highest S value represents the most alternative method.

$$S_i = \sum_{j=1}^{m} a_{ij} W_j \tag{5}$$

where $S_i$ is relative value of alternative A and m is the number of module results. The relative importance of each modular result can be decided by the subjective and intuitive assessment of decision makers and other stakeholders.

## RESULT AND DISCUSSION

An old pump (Pump A) aged with 8 year is operating in a petrochemical plant. At pump failure, the process shuts down and financial losses are incurred as each hour of down time results in a gross margin loss of US$10,000/hour of outage. The plant is planning to buy a new pump (Pump B) for a replacement of the old one the plant has an estimated 10 years life and the plant will be sold-out during this interval. The plant wants to make a decision either to buy a new one or to repair and maintain the old one. The data required for the analysis is extracted from (Waghmode. *et al*., 2010), (Hennecke. 1999), (A guide to LCC Analysis for pumping systems).

1. ABC-LCC

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All the activities which are the driver of the cost and their relation are identified as shown in the Table 1 below.

**Table 1:** Pump life cycle activities and cost drivers.

| Installation and commissioning | |
|---|---|
| Activity | Major cost drivers |
| Preparation of foundation | Personnel, time spent, and tools used |
| Grounding | Personnel, time spent, and tools used |
| Pump s*et al*ignment before pimping | Personnel, time spent, and tools used |
| Piping | Personnel, time spent, and tools used |
| Pump s*et al*ignment after piping | Personnel, time spent, and tools used |
| Electric connections | Personnel, time spent, and tools used |
| Commissioning | Personnel, and time spent |
| Operation | |
| Day to day supervision | Number of hours of pump operation, personnel, and labour |
| Day to day operation | Cost of energy and number of hours of pump operation |
| Corrective maintenance and repair | |
| Access to the failed component | Time to gain access to failed component, personnel, and tools used |
| Diagnosis | Fault isolation time, personnel, manuals, technical data, test equipments, and tools used |
| Repair/replacement | Actual hands on time to repair/replacement, personnel, equipments and tools used |
| Verification and alignment | Time spent, personnel and tools used |
| Disposal | |
| Pump disassembly | Time to disassemble pump, personnel, and tool used |
| Separation | Time spent and personnel |
| Part recovery | Quality of parts, and transportation cost |
| Disposing | Quality of material and cost of dumping |

***a. Acquisition cost:***

The acquisition cost contains C1 product planning, C2 engineering design, C3 product test and evaluation, C4 software's used, C5 design documentation and training, C6 raw materials, and C7 manufacturing….. etc. The general expression for the acquisition cost is;

$$C_{aq} = \sum_{j=1}^{j=7} C_j \tag{6}$$

The acquisition cost contains all the cost of pump set which is cost of pump; 5190, cost of motor; 23750, cost of base frame; 550, and cost of coupling; 250. All the costs are in dollar ($). With the given data the acquisition cost for the new pump, pump B is therefore equals $29740.

***b. Installation and commissioning cost:***

Since the old pump, Pump A is already installed it is only the installation cost of pump B will be calculated. The installation and commissioning task is subdivided into seven different activities, Table 2 show the related data of these activities.

**TABLE 2**: Activities and Cost Driver for Installation (Waghmode. *et al*., 2010),

| | Personnel | Time unit(h) | Cost/unit | Total cost | Tolling cost |
|---|---|---|---|---|---|
| Activity | B | B | B | B | B |
| Preparation of foundation | 5 | 8 | 6 | 240 | 15 |
| Grouting | 5 | 12 | 6 | 360 | 30 |
| Pump s*et al*ignment before piping | 4 | 4 | 6 | 96 | 15 |
| Piping | 4 | 4 | 6 | 96 | 15 |
| Pump s*et al*ignment after piping | 4 | 2 | 6 | 48 | 15 |
| Electric connections | 4 | 4 | 6 | 96 | 25 |
| Commissioning | 2 | 16 | 18 | 576 | 0 |
| Total | | | | 1512 | 115 |

The cost of all the activities can be as follows (Waghmode. *et al*., 2010),

$$I_C = \sum_{i=1}^{i=m} [(t_a . n_p . C_l) + C_{ti}] \tag{7}$$

where $I_c$ is the cost of installation, $t_a$ is the estimated time for each activities, $n_p$ is the number of labour needed for each activity, $C_l$ is the labor cost, and $C_{ti}$ is the cost of tooling for installation. Using the above equation and the given data, the total cost of installation is $1,627.

***c. Operation cost:***

The high impact cost drivers in this phase are number of operation hours, personnel, and cost of energy. The operation cost can be estimated using Eq (8) as shown blew.

$$C_{op} = t * (C_e(KW) + C_l) \tag{8}$$

where $C_e$ is cost of consumed energy ($/KWH) and $C_l$ is the labor cost for the operation per hour. Energy consumption is calculated by gathering data on the pattern of the system output. Cost of energy for pump can be estimated as shown below (Waghmode. *et al*., 2010), (Hennecke. 1999).

$$C_e = C_{pw}\left[\left(\frac{Q.H}{366.\eta_p.\eta_m}\right)\right] \tag{9}$$

where $C_{pw}$ is cost per input power ($/kw), Q is the pump flow rate ($m^3$ /h) which is 300 and 205 for pump A & B respectively , H is the pump head (m) 90 for pump A and 300 for pump B, $\eta_p$ is the pump efficiency which is 76 and 75 for pump A & B, $\eta_m$ is the motor efficiency 92 for pump A and 90 for pump B, the energy cost per KWh is $0.1KWh, and the labour cost of operation is $1/h, the total cost of operation for the life cycle is calculated using Eq. (9) and it is equal to $1,052,224 for pump A and $1,878,437 for pump B.

*d. Maintenance and Downtime cost:*

The failure data of the pumps is collected for the past four years for the old pump; Pump A. and it is eight failures are recorded within this time which is given in hour; the time of the failure is, 545, 1945, 3119, 3799, 4631, 5081, 6024 and 6900. Since there are no historical data for the new pump; Pump B, the failure data is taken from another plant that uses a similar kind of pump. The failure data collected is for the four consecutive years of the pumps first operation it is given in hours as follow; 3026, 4759, 5874, and 7015. Number of failure for repairable system depends on the repair assumption taken. The state of the repair assumption can be determined using general renewal process (GRP) model (Haryono. W. W.). There are two types of GRP models, type I and type II. In GRP type I model the system age of only the previous failure epoch i.e., the time between the previous two failures is improved. Let Vi denote the virtual age of the repairable system after the $i^{th}$ Corrective maintenance action, and let $V_0 = 0$. GRP type I virtual age model indicates that,

$$V_i = V_{i-1} + qY_i \tag{10}$$

where q is maintenance effectiveness $0 < q < 1$. $Y_1, Y_2, Y_3, Y_4 \ldots Y_n$, is the time between failure. Under this model, each corrective maintenance action removes a portion, $1 - q$, of the age accumulated during the most recent period of repairable system function. GRP type II model is extension of GRP type I model. The difference between them is on assumption about impact of repairing on the damaged incurred (Syamsundar. A *et al*., 2012). GRP typeII reflects the reality where the maintenance action reduces the cumulative damage of all the previous failures. It is governed by the following equation:

$$V_i = q(V_{i-1} + Y_i) \tag{11}$$

Note that if q = 0, then corrective maintenance is perfect, if q=1, then it is minimal and if $0 < q < 1$, then the corresponding repair assumption is somewhere in between perfect and minimal (Reliasoft publishing). Under this model, the time to repairable system failure is a Weibull random variable having scale parameters $\beta > 1$ and shape parameters $\eta$. As stated in Wahyu (Haryono. W. W.), maximum likelihood estimation (MLE) is more considered to estimate GRP model parameter ($q, \beta, \eta$). Greater the MLE value of the model, best will be the statistical fit for the given data. The scale and shape parameters of weibul and the meantime between failure and number of failure of pump are calculated for three repair assumption as shown in Table 3. Since the solution cannot be obtain analytically numerical methods is applied by Weibul ++8 software.

**TABLE 3:** Reliability Parameters, Mean Time between Failure and Number of Failures.

| | | Shape parameter β/month | Scale parameter α | MTBF | Number of failure |
|---|---|---|---|---|---|
| Pump A | Perfect repair | 3.123282 | 4.207e -10 | 901 | 97 |
| | In between | 2.924266 | 4.207e-10 | 788.3 | 112 |
| | Imperfect repair | 1.159694 | 0.000247 | 660 | 134 |
| Pump B | Perfect repair | 2.8842 | 2.0805e-10 | 2044 | 42 |
| | In between | 2.7803 | 2.0805 e-10 | 1513.6 | 57 |
| | Imperfect repair | 2.1332 | 1.8740e-08 | 655 | 134 |

Maintenance cost is therefore can be estimated using

$$M_c = T / MTBF\,(C_{s.p} + C_t + MTTR\,(l * n)) \tag{12}$$

where $T$ is the life span of the pump, $MTBF$ is the mean time between failure, $C_{s.p}$ is cost of spare part for repairing a failure, if the pump is repaired without replacing any parts $C_{s.p}$ is going to be zero. $C_t$ is cost of tools; $MTTR$ is mean time to repair, $l$ is cost per labor and $n$ is number of labor for each activity.

The cost of maintenance is estimated by the activities it performs. Given the cost of spare part is $200, tooling cost and mean time to repair for activities; access to the failed component, diagnosis, and verification and alignment is $3& 3hr respectively, and for activity repair/replacement it is $6 and 6hr respectively, number of personnel for all the activities is 4, and the cost per time for each personnel is $8. Perfect repair results in a

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higher expected cost, similarly the imperfect or the minimal repair will cause a minimum expected cost but will lead to an increase number of failure. However under the combination strategy parts which face major failure will get perfect repair while other parts which face minor failure will face an imperfect repair. This strategy seems to be a more practical and financially attractive choice and the maintenance cost is estimated for this assumption which is found to be $145040 for pump A and $73815for pump B.

***e. Net present worth:***

The total LCC of Pump A is 1197386 and for Pump B 1878437. The acquisition cost is made at the present time and doesn't need any discounting. It is assumed that the Installation will be finished within the next 6 month, which will be discounted period of the cost. The operation, maintenance and decommissioning cost are given to the total life of the pump and it will be considered as the future cost at the end of 10 yrs from now.

$$NPW_i = AC_i + C_{ic} * (1+i)^{-1/2} + (C_{op} + M_C).(1+i)^{-10} \quad (13)$$

The total net present cost is found to be 478954 for Pump A and 787221.9for Pump B.

*2. FAHP:*

The two pumps will be evaluated with three criterions this are Ease of Operation (EO), Safety (S) and environmental condition (ENV). Based on the documents and interviewing three experts let the pair wise comparison, the fuzzy evaluation matrix be as given (in triangular fuzzy) in Table 4.

**Table4**: Expert Opinion on the Criterion

| | EO | S | ENV |
|---|---|---|---|
| EO | (1,1,1) | (2/7,1/3,2/5) | (2/5,1/2,2/3) |
| S | (5/2,3,7/2) | (1,1,1) | (2/3,1,3/2) |
| ENV | (3/2,2,5/2) | (2/3,1,3/2) | (1,1,1) |

The first analysis is made between each criterion. The value of fuzzy synthetic extent with respect to the ith object is, SI, therefore for each criterion the extent value is represented by $S_{EO}$, $S_S$, & $S_{ENV}$

$S_{EO}$ = (1.686, 1.833, 2.067)* (9.019, 10.833, 13.067) $^T$
= (0.13, 0.17, 0.23)

$S_S$ = (4.167, 5, 5.5) * (9.019, 10.833, 13.067) $^T$
= (0.32, 0.462, 0.61)

$S_{ENV}$ = (3.167, 4, 5) * (9.019, 10.833, 13.067) $^T$
= (0.242, 0.37, 0.554)

Using the degree of possibility concept the compared weight value is found.

V ($S_{EO} \geq S_S$) = -0.44 V ($S_S \geq S_{EO}$) =2.55
V ($S_{EO} \geq S_{ENV}$) =-0.07 V ($S_S \geq S_{ENV}$) =1.33
V ($S_{ENV} \geq S_{EO}$) = 1.88 V ($S_{ENV} \geq S_S$) = 10.718

Thus the weight vector is found to be W'= (0, 1, 0.718) $^T$, through normalization, the weight vectors with respect to the decision criteria is found to be W= (0, 0.58, 0.417).

Next each Pump, Pump A ($P_A$) & Pump B ($P_B$) will be compared under each of the criteria separately. This is shown in the Tables 5 below.

**Table 5**: Expert Opinion on the Alternatives

| EO | PA | PB | | S | PA | PB |
|---|---|---|---|---|---|---|
| PA | (1,1,1) | (5/2,3,7/2) | | PA | (1,1,1) | (2/5,1/2,2/3) |
| PB | (2/7,1/3,2/5) | (1,1,1) | | PB | (3/2,2,5/2) | (1,1,1) |

| ENV | PA | PB |
|---|---|---|
| PA | (1,1,1) | (2/7,1/3,2/5) |
| PB | (5/2,3,7/2) | (1,1,1) |

Finally, adding the weights for each candidate and multiplying by the weight of the corresponding criteria, a final score is obtained that is 0.18 for pump A and 0.82 for pump B. Based on the ease of operation, safety and environment it is pump B that should be preferred. However it is necessary to incorporate the qualitative assessment with the quantitative one, the next section deals with the weighted sum model to incorporate these assessments.

*3. Weighted sum model:*

As stated above WSM is used to compare to incomparable attributes and serves to obtain a final decision which changes the two modular results into weighted factors that are standardised to be calculated. The summary of the two modular results are shown in Table 6 below. The weight factors were calculated based on Eq (5)

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**Table 6:** Table Summary of final and normalized assessment result.

| | Summary of assessment result | | Summary of normalized assessment result | | | |
|---|---|---|---|---|---|---|
| | FAHP | ABC-LCC | FAHP | ABC-LCC | Total | Prioritization |
| PUMP A | 0.18 | $ 478954 | 0.18 | 1 | 1.18 | 1 |
| PUMP B | 0.82 | 787221.9 | 0.82 | 0 | 0.82 | 2 |

***Conclusion:***

A decision support model is model is developed by integrating the concept of ABC-LCC and FAHP using WSM. Activity based method is used to identify the activities and cost drivers in acquisition, operation and maintenance phase and FAHP is used to incorporate the subjective assessment. Two Pump sets, Pump A (the existing one) and Pump B (the new one) is taken as a case for this paper. The acquisition cost of the new pump; Pump B is found to be less than 1.2% of the total LCC, which shows that it is necessary to have a long-term outlook to the investment decision-making process rather than trying to save money in the short-term by simply purchasing assets with lower initial acquisition costs. The operation cost is the highest cost for both the pumps which is in between 88 to 93%. The maintenance cost is the highest for the old pump; Pump B, due to its aging failure. The number of failures which incur maintenance cost is determined for three maintenance assumptions; that is when the repair condition is as good as new, as bad as old and when it is in between. The number of failure is calculated by using the GRP. The minimal repair strategy for all components results into lower expected cost while perfect repair strategy for all components results into higher expected cost. From the output of the ABC-LCC it is found that Pump A has higher total cost, however the result of the FAHP shows that Pump A has a lower priority. Using WSM as a final decision making method pump A is selected. That means the final decision is to continue working with the old pump rather than buying a new one.

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